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Gianni Guastella[1],
Stefano Pareglio[1,2]

[1] *Università Cattolica, Research Center on Environment, Energy and Sustainable Development, Italy*
[2] *FEEM, Fondazione Enrico Mattei, Italy*

E-mail:giovanni.guastella@unicatt.it, stefano.pareglio@unicatt.it

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Urban spatial structure and land use fragmentation: the case of Milan FUA*

We study the relationship between urban spatial structure and land use fragmentation in the Functional Urban Area (FUA) of Milan to understand if and how the urban morphology influences the patterns of land use at the metropolitan scale. Using Exploratory Spatial Data Analysis, we find that the spatial structure of the urbanisation in the study area follows the traditional monocentric distribution in the south while multi-centricity characterises the north to the largest extent. Findings suggest clearly that different urban spatial structures lead to diverse patterns of land use. In particular, it appears that the degree of discontinuity of residential areas is lower in the presence of secondary sub-centres compared to the mono-centric distribution.

1. Introduction

With the introduction of the concept of functional regions, city regions, and functional urban regions (see respectively Klapka et al. (2013), Scott (2002) and Limtanakool et al. (2007) for recent overviews and conceptualizations), the central role of Functional Urban Areas (FUAs), defined as labour market basins, emerged in the academic and policy debate concerned with the socio-economic development of territories in Europe (Cheshire and Carbonaro 1996; Cheshire and Magrini 2000; Cheshire and Magrini 2006). Although the FUAs do not correspond to a unique and precise definition of administrative units at the European level, their central role appears in the number of projects the European Territorial Observatory Network (ESPON) carried out to track and monitor the development of the major cities in Europe and their surrounding areas. In this regard, the year 2012 marked an important step toward the definition of these spatial entities in Europe with the joint adoption by the Organization for Economic Co-Operation and Development and the European Commission of a consistent definition of metropolitan areas based on labour market integration (OECD 2012). FUAs, in fact, represent the core of the European economic activity being, at the same type, the places where the urban and rural characters of the territories mix and overlap.

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The concept of functional integration is the building pillar of this conceptualization, relatively new in Europe compared to the trans-Atlantic tradition. Accordingly, home-to-work flows of commuters define the functional linkages between the core of the FUA and the remaining areas, reflecting the traditional compact monocentric organisation of European Union (EU) cities (Patacchini 2009). A recent study by Schneider and Woodcock (2008), however, documented that the concept of FUA does not correspond uniquely to the monocentric structure, and that, in contrast, FUAs in EU cities show very different urban morphologies, characterised by urban dispersion, or fragmentation, or multicentricity. Findings in Garcia-López and Muñiz (2010) and Veneri (2013) corroborate the evidence that the urban structure of the EU cities is increasingly departing from the monocentric morphology and evolving toward more dispersed and multi-centric ones. The dramatic decrease, in the second post-war period, of unitary transportation costs, partly to ascribe to the extension of the road and rail networks and partly a consequence of the spread of cars among medium-low income households, is responsible for this shift toward the spreading of the residential settlements. To some extent, it is the social response to the need to combine increasing agglomeration in cities with changes in lifestyles and housing preferences (Davoudi 2003). While urban cores maintain the central functions and attractiveness, people may prefer larger houses in the urban peripheries or sub-districts, leading to complex cross-commuting. Among the others, the result of this decentralisation is that population in the core of EU cities, in general, is shrinking, but the modes and intensities of such shrinking vary across cities and are related, among the others, to the urban structure (Haase et al. 2016).

Urban sprawl, intended as an excessive and often unnecessary agricultural and natural land take for low-density urbanisation, is one of the side effects of the spatial expansion of cities, as it often comes at the expenses of the environment, treating the ecological equilibria (Bengston et al. 2005). Sprawl is often associated with traffic congestion, which is responsible for increased fatality rates of road accidents and increased air pollution; with the loss of green spaces and landscape deterioration; and, above all, with leapfrog urban development, that is the lack of physical continuity necessary to some natural processes (Hogan and Ojima 2008). Furthermore, the farmland conversion for new housing and infrastructure (soil sealing) is an irreversible process, and irreversible are also the consequences regarding the soil functions: loss of water permeability, loss of soil biodiversity, deterioration of the ecosystem services provided, and reduction of the capacity for the soil to act as a carbon sink (European Environment Agency 2006). Hence, there are arguments in support of the compact cities, in which the high urban density brings significant advantages not only regarding soil consumption (Guastella and Pareglio 2014) but also transportation efficiency through lower commuting distances and work-life balance through less time spent on commuting. Similar arguments do not extend to the quality of the environment, as compact cities experience substantially higher air pollution and lower inner land preservation, even though some research pointed to trade-offs between local and regional performances (Whitford et al. 2001). Accordingly, the high environmental quality in the

outer territories of dense and monocentric urban structures rewards the poor environmental standards in the inner cities.

The phenomenon of urban sprawl does not show uniquely morphological characters. Instead, sociologists, urbanists, and geographers attribute specific social characters to the concept. For instance, the geographical area of interest in this study has been analysed in Colleoni and Caiello (2013). The authors concentrate their attention on peri-urban areas, that are also the areas most subject to the urbanisation pressures and argue that, in these territories it is possible to distinguish the typical urban characters related to the presence of built-up area, tertiary occupation, intense mobility and urban lifestyles. But, differently from the inner cities, peri-urban areas do not show the typical urban density, contiguity, and heterogeneity. According to the authors, this increasing settlement dispersion characterised the urban spatial expansion in western countries but in their work they document a strong relationship with some specific socio-demographic changes in the distribution of households.

Against this background, a polycentric urban structure appeared as a social and environmental-friendly alternative to the sprawled, fragmented, and dispersed urban morphology (Hogan and Ojima 2008), capable of promoting the economics of agglomeration and urbanisation at low social and environmental costs. The polycentric structure, which origins date back to the Central Place Theory (Christaller 1966; Lösch 1954), is a multi-centric structure characterised by the substantial functional integration of cities network-distributed cities in the urban system. Cities perform different functions according to the relative hierarchical position in the urban system (Craig et al. 2016) and agglomeration externalities spread through the network structure instead of operating as a result of the spatial concentration of economic activities (Meijers 2005). The essential characteristic is the presence of suburban centres that combine the existence of important functions with the supply of larger houses at lower rents to the households, reducing the average commuting distance and the costs of transportation and, hence, improving the work-life balance of households.

Polycentric urban systems are also described as more environmentally sustainable forms of urban organisation: the presence of medium size cities within the system works as a deterrent of excessive urban dispersion (Catalán et al. 2008), preserving the ecological functions of soil from the risks of excessive spatial dispersion of urban settlements. For this reason, the literature distinguishes the polycentric urban expansion from the wider concept of urban dispersion (Davoudi 2003). Concerning the EU cities, Patacchini et al. (2009) document that dispersion more than polycentric organisation represents the most common trend, strengthening the argument that compact urban development, even when desirable and pursued, is not easily achievable (Breheny 1997).

In particular, the spatial dispersion of residential settlements, otherwise known as urban fragmentation, that is the relative incidence of discontinuous urbanisation, appears the problem of European urban growth: based on Kasanko et al. (2006), the experience of EU cities tells that built-up area has growth even if population declined, and almost all the newly built areas are discontinuous. A

consolidated empirical evidence related the urban spatial structure to the pattern of land use change (Schneider and Woodcock 2008), opposing the heterogeneous distribution of the high-density monocentric model to the most homogeneous distribution of medium densities in the polycentric model. In particular, the area expected to undergo continuous urban sprawl may be higher in the case of a monocentric structure (Salvati 2014), and the urban expansion following the monocentric structure may be a favourable condition to achieve reduced land consumption and increase land use efficiency only in specific socio-economic contexts (Salvati and Carlucci 2014).

In this work we document the relationship between urban spatial structure and the degree of urban fragmentation in the FUA of Milan. We apply spatial statistics to a 1km grid of population density in 2011 to explore the spatial patterns of urbanisation. Within the FUA, we distinguish two main urban spatial structures. Considering the core of the Milan city as the centre of the FUA, findings reveal that population density monotonically decreases moving in the southern part of the FUA, delineating the typical pattern of a monocentric structure, while it interrupts with suburban centres in the north-eastern and north-western parts of the area, framing a multi-centric structure. Applying a fragmentation index computed on the base of 2012 residential land use data we find evidence suggesting that a higher fragmentation characterises the mono-centric part of the area compared to the multi-centric one.

The remainder of the paper is organised as follows. In section 2, we introduce the methodology for the spatial analysis of grid population data and present the results of the application to the FUA of Milan. In section 3 we present the findings of the relationship between urban morphology and urban fragmentation. A discussion of these results and their implications concludes the work, in section 4.

2. Exploratory Spatial Data Analysis

The study area of this paper is the FUA of Milan, the largest city of the Lombardy region, the second Italian city by total population. To identify the territories that belong to this area we employed the EC-OECD definition of Large Urban Zone (LUZ). The LUZ is formally acknowledged as a relevant territorial unit and, at this territorial level, Eurostat provides economic and demographic information in the Urban Audit database (http://ec.europa.eu/eurostat/statistics-explained/index.php/European_cities_-_spatial_dimension). The precise physical boundaries of the area are delineated by the map available in the Urban Atlas collection provided by the European Environmental Agency (http://www.eea.europa.eu/data-and-maps/data/urban-atlas). Superimposing this map to the GEOSTAT grid map of 2011 population in Europe we obtain the population grid of the LUZ of Milan.

To study the urban spatial structure of the LUZ of Milan, we apply the Exploratory Spatial Data Analysis (ESDA) techniques (Anselin 1996). The methodology allows identifying spatial clusters of units with similar characteristics; that is spatial clusters of high (low) population density areas. If a city follows the typical

monocentric structure, we expect a small cluster of high-density grids in the core and a large cluster of low-density grids out of the core (the periphery), that is the fringe of the LUZ. The methodology also allows identifying alternative spatial patterns, such as cases of high-density grids surrounded by low-density grids or the opposite cases. In particular, the case of high-low density patterns is especially relevant to identify the suburbs of a multi-centric urban structure.

In summary, the methodology works as follows. For a given variable x the average of x in the neighbouring units is computed by pre-multiplying the variable with the spatial weight matrix W. This is a transformation of the spatial contiguity matrix C, an n-dimensional square matrix, n being the number of spatial units observed, which row-column element is different from zero if the unit in row and the unit in column are neighbours. Contiguity is defined using physical boundaries, or taking the k-nearest units, or taking all the units within a cut-off distance d. For the purpose of this study the physical boundaries are used. The elements of the matrix are binary operators indicating contiguity (1) or not (0) and, as usual in these applications; self-contiguity is not included. When the contiguity matrix is row standardised, the spatial weight matrix is produced, its generic elements is

$$w_{ij} = \frac{c_{ij}}{\sum_i c_{ij}} \tag{1}$$

and is interpreted as the relevance of unit j for unit i, relative to the other neighbouring units of i.

The slope of a linear regression of Wx on x after demeaning both variables is the Moran Index of spatial autocorrelation (Moran 1950), a generic indicator of the degree of spatial association present in the data, from which the local, unit-specific, version, the Local Indicator of Spatial Autocorrelation (LISA) (Anselin 1995) can be derived. The meaning of this indicator can be explained using a Cartesian plot, the Moran scatterplot, in which the two dimensions are crossed, leading to four possible combinations of spatial patterns, which are:

1. High-High, that means that the value of the variable is higher than the average both in the units and its neighbouring units;
2. High-Low, that means that the value of the variable is higher than the average in the unit and lower than the average in the neighbouring units;
3. Low-High, that means that the value of the variable is lower than the average in the unit and higher than the average in the neighbouring units;
4. Low-Low, that means that the value of the variable is lower than the average both in the unit and in the neighbouring units.

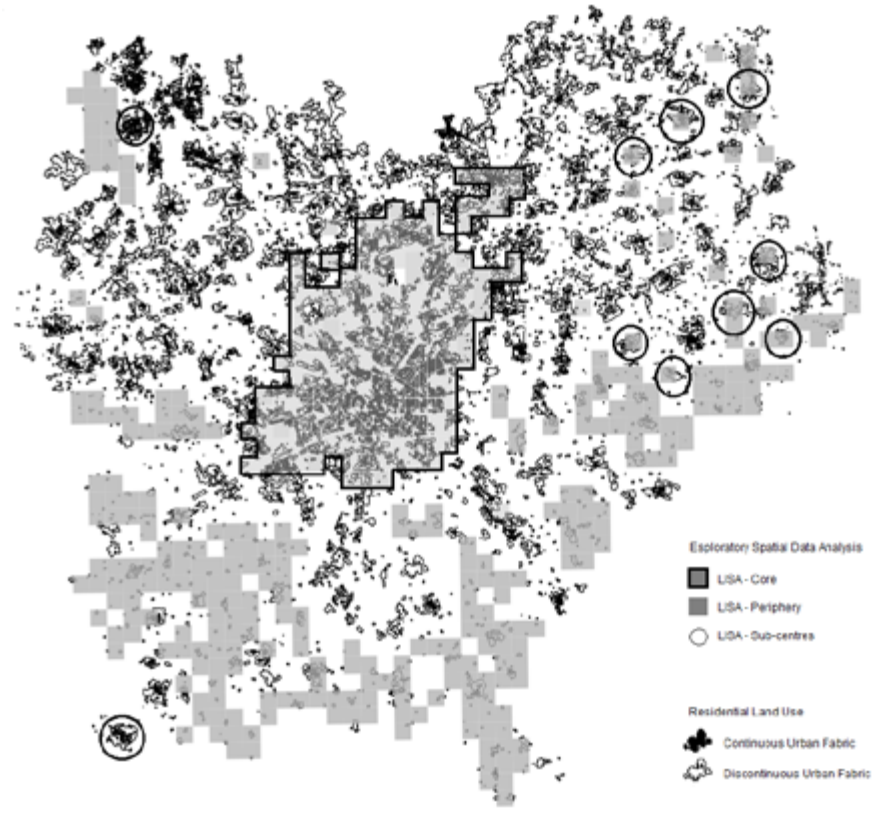
The approach has been proposed in the urban economics literature as a methods for the identification of sub-centres (Baumont et al. 2004; Guillain et al. 2006) in alternative to methods based on simple and arbitrary measures of population and employment density (Cervero and Wu 1998; Muñiz et al. 2008; Small and Song 1994) or employment-resident ratio (Shearmur and Coffey 2002). Páez and Scott (2005) provide a complete review of these methods. However, the proposed meth-

od is deemed superior as it shows a clear advantage over the other approaches, in that it is not only useful for the identification of sub-centres but also provides a complete and detailed description of the urban spatial structure of the study area.

The results are presented in Figure 1, relatively to only the significant values of the LISA indicator. The grey area defined by a black border is the core of the LUZ of Milan, hence the cluster of units where the population density is significantly higher than average and neighbouring units. This corresponds to the *High-High* pattern in the classification above. In the southern fringe of the LUZ emerges the periphery as a homogeneous strip of contiguous units characterised by a population density significantly lower than the average. This corresponds to the *Low-Low* pattern in the classification above. The northern area seems instead characterised by the presence of a substantial number of sub-centres, that is units with significantly higher than average density but that are not clustered with other high-density units. This corresponds to the *High-Low* pattern in the classification above.

Accordingly, while the southern part of the area reflects the most typical characteristics of the mono-centric organisation of cities with high density in the core

Figure 1. Exploratory Spatial Data Analysis of the Milan LUZ.



and low density in the periphery, in the northern part a multi-centric structure best represents the urban morphology.

In the same map, we included information about the continuous (filled black) or discontinuous (filled white) character of the residential urban fabric to initially describe the relationship between this character and the urban spatial structure. The information about residential land use is taken from the Database of Agriculture and Forestry Soil Use (DUSAF) and refers to the year 2012, the most recent. Note that the definition of continuous and discontinuous urban fabric employed considers the residential land use only, because the distinction between continuous and discontinuous is not provided for other typologies of urbanised area.

The information on the presence of continuous or discontinuous residential urban fabric brings interesting insights about the urbanisation structure, as it is evident from the map that in the core of the LUZ urbanisation is mostly represented as continuous, while significant discontinuity is noticeable in the rest of the area outside the core. Hence there is evidence that urban expansion outside the core has more relevant consequences for the environment, not only because of the average density decline, and hence every household consumes marginally and more soil, but also because there is less territorial continuity in the agricultural and natural areas.

3. Urban spatial structure and residential land use fragmentation

Having understood that outside the urban core urbanisation is more fragmented, we move forward with the empirical investigation asking to what extent the urban morphology, hence the mono-centric vs. multi-centric organisation of urban space, has an impact on the spatial structure of residential land use. For this purpose, we aggregate the DUSAF information on soil use (continuity/discontinuity of residential built up area) at the grid level and compute the following index of urban fragmentation

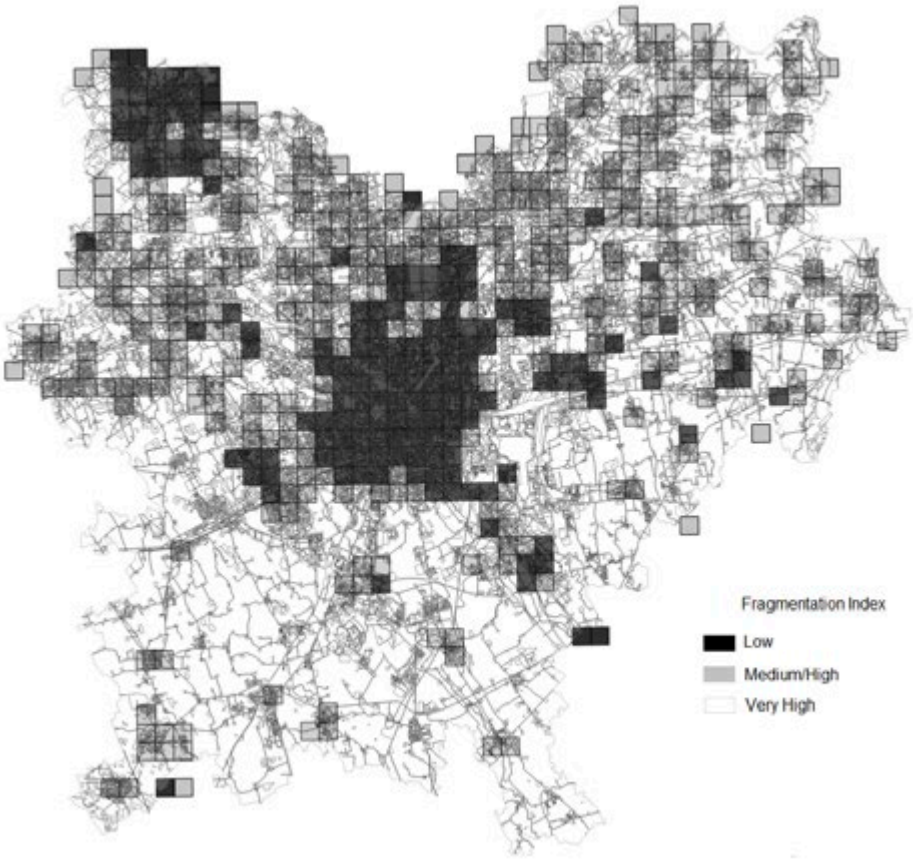
$$frag = \frac{duf}{cuf}$$

where *duf* is the total area in the grid classified as discontinuous urban fabric and *cuf* is the total area in the grid classified as continuous urban fabric.

Figure 2 maps the urban fragmentation index classifying all the grids in three groups:

1. low fragmentation, is where the fragmentation index is lower than one, meaning that urban compactness is the most relevant character of the area;
2. medium/high fragmentation, is where the fragmentation index is higher than one, meaning that urban discontinuity is the characterising feature;
3. very high fragmentation, is where fragmentation index is unreasonably high because the value of *cuf* approaches to zero.

Figure 2. Map of the fragmentation index in the Milan LUZ.



Based on this classification, the evidence in figure 2 confirms the result in the previous figure, according to which urbanisation is more compact in the LUZ core compared to the area outside the core. But the figure also adds new insights. In particular, in the north, where the urban spatial structure appears multi-centric, the incidence of medium/high fragmentation area is high. In contrast, the incidence of medium/high fragmentation is substantially lower in the south, where the urbanisation pattern is mono-centric and very high fragmentation dominates. Considering the north only, a relatively lower fragmentation emerges where the LISA indicator identifies sub-centres, meaning that these places have not only the demographic characters of cities, the high population density but also their morphological character, the compactness of built-up residential area. Oppositely, in the south, even in centres where the population density is relatively high, urbanisation remains largely discontinuous.

To compare more accurately the spatial distribution of continuous and discontinuous residential land use among the different areas of the FUA, and to relate these differences to overall urbanisation, we present in Table 1 some descriptive statistics at the aggregate level, distinguishing the core of the FUA, the multi-centric areas, and the mono-centric area.

Table 1. Descriptive statistics of urbanisation and urban fragmentation in the FUA of Milan.

	Continuous urban fabric	Discontinuous urban fabric	Total residential	Infrastructures	Total urban	Agricultural land	Natural land
Core							
levels	42057002	33083639	75140641	9721049	166757376	18594033	1679300
% urban	25,22%	19,84%	45,06%	5,83%			
% total					88,95%	9,92%	0,90%
Multi-centric area							
levels	40170699	183914010	224084709	71706988	557241595	540951329	96270571
% urban	7,21%	33,00%	40,21%	12,87%			
% total					46,39%	45,04%	8,02%
Mono-centric area							
levels	6919494	56936164	63855658	4673734	148882417	574690939	42487903
% urban	4,65%	38,24%	42,89%	3,14%			
% total					19,33%	74,63%	5,52%

In the core of the FUA, continuous urban fabric occupies 25,22% of the total urban area while only 19,84% of the urban area is occupied by discontinuous urban fabric, leading to very low fragmentation, on average. As much as 89% of the total area is urbanised, and the agricultural area represents only less than 10% of the soil. Moving to the multi-centric area, the share of continuous urban fabric decreases to 7,21% only, although the figure is substantially higher than that relative to the mono-centric area (4,65%). In contrast, the share of discontinuous urban fabric is lower in the multi-centric than in the mono-centric area. Overall, the index of urban fragmentation in equation 2 computed on the aggregate measures almost doubles moving from the multi-centric to the mono-centric area. The higher fragmentation in the mono-centric area corresponds, however, to an overall lower level of urbanisation. Urban land in the mono-centric area accounts in fact for less than 20% of total area, while the majority of land is used for agricultural activities (74,63%). The figure more than doubles in the multi-centric area (46,39%) to the detriment of agricultural land, which now accounts for only 45,04% of the total.

4. Discussion and conclusion

By linking urban spatial structure to the discontinuity of residential land use patterns in the case study area of Milan, this paper brings additional evidence to the literature investigating the impact of urban forms on the land take. The paper sets out an empirical analysis to understand if the morphological characters of the compact city, that are the high densitiy and the spatial concentration around a central district, are related to the fragmentation of residential land use. In this respect, the focus of the analysis is ultimately on the morphological aspects, leaving aside the discussion on the sociological and environmental consequences of alternative morphologies. Although we present empirical findings of descriptive nature which cannot serve to establish any causal relationship, the evidence associates the monocentric urban development to a more substantial incidence of discontinuity of residential land use.

Findings suggest that the monocentric structures are compact in the immediate neighbourhood of the centre, but urbanisation became very dispersed and fragmented moving far from the centre, although the impact on total land use is relatively low. In contrast, in multi-centric structures, the presence of suburbs promotes more heterogeneous urbanisation patterns but also a more efficient process of land transformation compared to the monocentric structure. This evidence suggests that urbanisation is relatively more discontinuous in a monocentric structure, questioning the idea that a monocentric structure can more effectively promote the compact urban development. Following Breheny (1997) it is unclear (and we add difficult to assess quantitatively) the extent to which the compact city brings real environmental benefits regarding reduced energy consumption and, indirectly, emissions (see also Breheny 1995). But, based on the empirical evidence reported by ecological studies, a non-compact urban development has more severe ecological consequences because continuity is necessary to ensure the correct functioning of ecological functions of soil, and more generally the provision of ecosystem services (Bengston et al. 2005).

As a conclusion, there is still no clear indication on whether the traditional monocentric urban structure should be preferred to the more contemporary – and promoted – multi-centric structure or whether urban planners should obstacle the city transformation in this direction. If on the one hand, the emergence of peripheral suburbs causes intensive land take and soil sealing, on the other, polycentric sub-urbanisation is associated to a lower residential discontinuity, hence, to a higher efficiency in soil use at the regional level.

The extent to which one urban spatial structure may show superior to the alternatives relates strictly to the characteristics of the territory, which are site-specific, and accordingly, the evaluation cannot be generalised. In a context where the presence of suburban centres that shape the multi-centric structure does not represent a specific planned outcome but instead results from the natural re-organization of traditional monocentric cities and their transition toward spatially enlarged structures, it also makes little sense the debate itself about which urban spatial structure should be preferred. To move beyond this mono-centric vs. multi-

centric paradigm comparison it is important to shed light on the allocation efficiency of land to preserve the free soil reserves from the risk of excessive fragmentation and loss of ecological functions.

The evidence put forward in this paper hence calls for an evaluation of planning that not only takes care of the amount of soils used for urbanisation, but that also pays proper attention the efficiency of its use, evaluated also considering the current urbanisation patterns.

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